Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Aerospace Medical Research Laboratory, Aerospace * Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio 45433.

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
BABOON TOLERANCE TO LINEAR DECELERATION ($-G_x$): LAP BELT RESTRAINT.

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Reprinted from the Stapp Car Crash Conference. (14th). Univ of Mich. 17-18 Nov 1970.

5. AUTHOR(S) (First name, middle initial, last name)
Thomas D. Clarke, Harold S. Klopfenstein, Charles D. Bendixen, James F. Sprouffske, William H. Muzzy, Edwin M. Trout, C. D. Gragg

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
	20	25

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 7231	AMRL-TR-72-44
c. Task No. 723106	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES
*This project effort was transferred from 6571st Aeromedical Research Laboratory, Holloman AFB, New Mexico to Aerospace Medical Laboratory, Wright-Patterson Air Force Base, Ohio 45433.

12. SPONSORING MILITARY ACTIVITY
Aerospace Medical Research Laboratory, AMD, AFSC, Wright-Patterson Air Force Base, Ohio 45433.

13. ABSTRACT

The tolerance to abrupt linear deceleration ($-G_x$) and the subject response to a lap belt restraint system were investigated. Nineteen adult male baboons comprised the test pool. The effects of impacts of 8.6-40 g were studied, with nonsurvivability used as the index of tolerance.

The results indicated that the tolerance to impact (LD_{50}) approximated a 32 g sled deceleration. Lethality was presumed attributable to the secondary impact as the head contacted the floor of the sled. Predominant lethal injuries included avulsion of the atlanto-occipital articulation and dislocation fractures of the cervical vertebrae with resulting transection of the spinal cord.

Excellent linear correlations were established between peak lap belt and seat pan forces versus maximum sled deceleration. Likewise, a linear relationship was found between peak head angular accelerations and maximum sled deceleration.

21

Best
Available
Copy

700906

Baboon Tolerance to Linear Deceleration ($-G_x$): Lap Belt Restraint[1,2]

Thomas D. Clarke, James F. Sprouffske, Edwin M. Trout, Harold S. Klopfenstein, William H. Muzzy, C. D. Gragg, and Charles D. Bendixen

6571st Aeromedical Research Laboratory
Holloman Air Force Base, New Mexico

Abstract

The tolerance to abrupt linear deceleration ($-G_x$) and the subject response to a lap belt restraint system were investigated. Nineteen adult male baboons comprised the test pool. The effects of impacts of 8.6-40 g were studied, with nonsurvivability used as the index of tolerance.

The results indicated that the tolerance to impact (LD_{50}) approximated a 32 g sled deceleration. Lethality was presumed attributable to the secondary impact as the head contacted the floor of the sled. Predominant lethal injuries included avulsion of the atlanto-occipital articulation and dislocation fractures of the cervical vertebrae with resulting transection of the spinal cord.

Excellent linear correlations were established between peak lap belt and seat pan forces versus maximum sled deceleration. Likewise, a linear relationship was found between peak head angular accelerations and maximum sled deceleration.

[1]Animals in this study were handled in accordance with the "Guide for Laboratory Animal Facilities and Care" as published by the National Academy of Sciences, National Research Foundation.

[2]The opinions, findings and conclusions expressed in this paper are those of the authors and not necessarily those of the United States Air Force or the United States Department of Transportation.

AIR FORCE: 26-4-72/100

THE DYNAMIC IMPACT RESPONSE of animals (1, 2)[3] and humans (3-5) restrained with a shoulder harness has been well evaluated. Forces transmitted to the restraint webbing and the efficacy of altering the seat pan angle were particularly emphasized. Detailed analysis of the lap belt system has generally been disregarded since the advent of more sophisticated restraint devices. Although limited lap belt performance data have recently been obtained using dummies (6, 7), animals (8, 9), and humans (10), perusal of the literature revealed a paucity of engineering and pathological information.

A series of comparative investigations was conducted to assess the biodynamic aspects and the protection from impact trauma provided by the lap belt, shoulder harness, and air bag restraint systems. In this report the objectives were to determine a lethal tolerance by exposure to abrupt linear deceleration ($-G_x$) and to define principles of dynamic interaction of the subject with a lap belt restraint system.

Materials and Methods

Twenty-nine deceleration tests were performed with 19 adult male baboons (*Papio anubis*) weighing in excess of 45 lb (mean of 51 lb). Tolerance to impact (LD_{50}) was determined by sequential testing: each baboon was impacted at a 3 g increment below or above the deceleration of the previous test, respectively depending upon whether there was or was not a fatality within 3 hr on the previous test. The primary advantage of this method was the concentration of testing near the tolerance level, thus increasing the accuracy of LD_{50} estimation (11, 12). The LD_{50} was that level where impact fatalities were expected in 50% of the animals.

The experiment was conducted on the Daisy Decelerator (13), utilizing a 2830 lb sled. Entrance velocities ranged 24.8-53.8 ft/sec, onset 103-984 g/sec, and peak sled deceleration 8.6-40 g (Fig. 1). The impact pulse was approximately half sine with the stopping distance maintained constant at 2 ft resulting in total pulse durations of 0.080-0.213 sec. The interval from time zero to peak sled deceleration approximated one half of the total pulse duration (Fig. 2).

Animal Preparation Prior to each impact test, the subject was premedicated with 1 mg/kg body weight of Sernylan and 0.4 mg atropine. Anthropometrics were obtained before each test, as were samples of blood, urine, and cerebrospinal fluid. Following a physical examination, the hair was clipped to assure improved visualization of subject displacement during the impact event.

[3]Numbers in parentheses designate References at end of paper.

After positioning the animal on the sled, sodium pontobartibal was administered to obtain surgical anesthesia. The baboon was muzzled to eliminate lingual injury, and the wrists and ankles were taped to prevent flailing. The baboon torso was maintained in a proper sitting position by a strap around the thorax and seat back. This strap did not contribute as a restraint during impact since it was mechanically released less than 0.1 sec before the deceleration pulse. Masking tape was employed to hold the head against a headrest prior to impact. The inertia of the head broke the tape during the initial phase of the impact.

Whole body radiographic coverage and a physical examination were performed immediately post-impact in order to delineate fractures and gross trauma. Blood, urine, and cerebrospinal fluid samples were likewise

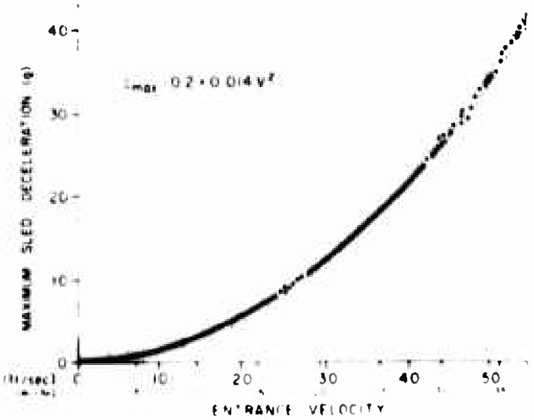

Fig. 1—Maximum sled deceleration versus sled entrance velocity. Shaded area represents the 90% confidence interval

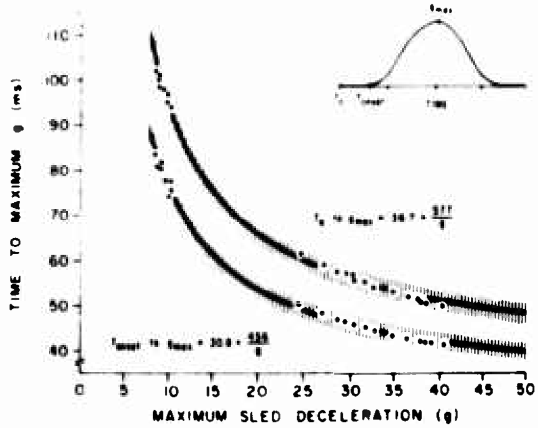

Fig. 2—Time to maximum sled deceleration from time zero and onset of deceleration pulse versus maximum sled deceleration. Shaded area represents the 90% confidence interval

obtained to provide indications of enzyme alterations, bladder, brain, and spinal cord injuries, respectively. Gross necropsy was conducted within 1 hr post-impact for the terminated subjects or 24 hr later for the surviving animals. Animals receiving less than 20 g were not euthanized because of the absence of traumatic injuries.

Instrumentation The baboon seat and restraint system was reduced proportionately from human seat and belt dimensions. The seat pan was horizontal and the back was 13 deg from vertical (Fig. 3). A 1 in. thick cushion — foam rubber covered with plastic — was affixed to the seat pan. Although a foot rest was not employed, a popliteal angle of 132 deg was consistently maintained. The floor of the sled was padded with 3 in. of Ensolite.

The rigid seat pan was instrumented with strain gages to provide independent outputs of forces translated fore-aft, lateral, and down, independent of the point of application. The rigid seat back was similarly instrumented for force determination in the up-down, lateral, and aft directions.

The lap belt angle was 50 deg to the plane of the seat pan. One in. Dacron webbing of 3700 lb tensile test was fitted around the abdomen in an arc of 165 deg, and statically tensioned for each side at approximately 10 lb. Each lap belt attach point was instrumented with a triaxial load cell which measured forces in three axes and enabled calculation of resultant force magnitudes and directions.

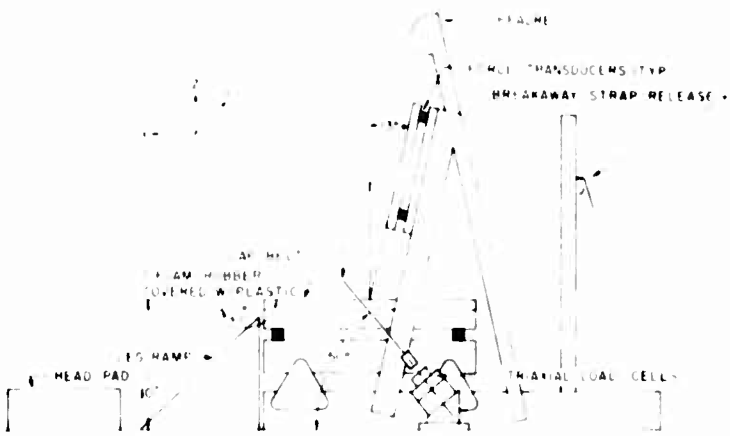

Fig. 3—Experimental seat layout

Photography — Photographic coverage included use of three 16 mm cameras operated at 2000 frames/sec and a 35 mm camera operated at 500 frames/sec. One 16 mm camera was mounted 13 ft vertical to the impact area; the remaining cameras were located 40 ft normal to the deceleration area in the same horizontal plane. Coded timing was recorded on all film. Pre- and post-impact 4 x 5 still photographs were routinely obtained for reference.

To assess the kinematic response of the subjects during the impact event, 1 in. diameter black targets were positioned on a contrasting background of adhesive tape (Fig. 4). The targets were located 2 and 6 in. proximal to the lateral epicondyle of the femur, adjacent to the greater tubercle of the humerus, and on a lightweight plastic head mount (anterior to the glabella and posterior to the external occipital protuberance). The laterally oriented cameras recorded the displacement of the targets during the impact.

Data Collection — All data were transmitted via a 130 ft umbilical cable from the sled to amplifiers and recording equipment in the blockhouse. Data channels were calibrated just prior to each test, using a resistive shunt technique. During the test, transducer outputs were excited, balanced, and amplified via a high impedance differential amplifier, and filtered at 100 Hz. Use of a low-pass filter improved the legibility of the data traces with no appreciable loss of response (13). Analog recordings were made on oscillographs and magnetic tape recorders. Event markers and coded timing were recorded on all film, oscillographs, and magnetic tapes to facilitate the exact time correlation of data.

Sled velocity immediately prior to impact was determined by timing the interval as the sled transversed 1 ft. An accelerometer was rigidly mounted to the sled frame for measurement of vehicle deceleration.

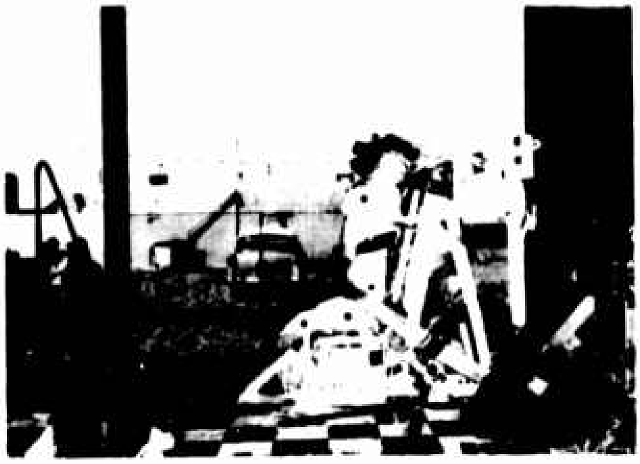

Fig. 4—Baboon seated on sled before impact (run 4882)

Data Reduction — The analog tapes were Gaussian filtered at 110 Hz and digitized at a rate of 1000 samples/sec by an A/D converter. The identification of calibration times was determined manually. Calibration values and corresponding times were card punched and input simultaneously with the digitized output on a CDC 3600-3800 digital computer complex. Phase shift due to filtering was time corrected to the photometrics. The final analysis program generated 1 ms listings of input data and analytical calculations, plus plots of all force components and resultants with respect to time.

During the impact event, displacements of body targets relative to the sled were obtained from the 35 mm film via an automatic film reader mated with a digital computer. The angular displacement of the head was derived from the instantaneous axis transecting the two targets located on the plastic head mount. From this displacement curve, angular velocities and accelerations of the head with respect to time were computed via differentiation.

Head Accelerometers — Affixed to the anterior and posterior flanges of the plastic head mount were mutually perpendicular triaxial accelerometer clusters. Head angular accelerations in a spatial reference system were calculated from two of the linear acceleration components (14). Integration of head angular acceleration by the computer yielded a plot of angular velocity versus time. Angular displacement of the head was computed by an additional integration.

Results and Discussion

The authors recognize that significant differences between impact responses of animals and humans may exist. Any extrapolation of results to human biodynamics should be made cautiously.

Although a total of 29 tests were performed, equipment malfunctions (severed lap belt, release failure of torso strap, etc.) and pre-impact cancellation of specific data channels resulted in deletions of some recorded data. Likewise, on all graphs individual data points may represent more than one deceleration test because of overlapping data.

Tolerance — The impact tolerance of animals has been expressed as a function of velocity, deceleration, or onset (2, 15-17). In this report the tolerance to impact was expressed as the percentage of subjects not surviving the effect of sled deceleration. Employing probit analysis (18), the median lethal sled deceleration (LD_{50}) was calculated to be 32 ± 4 g (Fig. 5). The validity of the regression line was confirmed by a Chi-square test (18) and was in close agreement with previous studies (8, 9).

The distribution of baboon injuries closely coincided with the reported trauma resulting from motor vehicle accidents (19, 20). Although details of the pathology will be reported in a subsequent paper, the predominant injuries included abrasions and contusions of the anterior abdominal wall, ruptured urinary bladders, pelvic fractures, brain stem hemorrhage, cranial fractures, avulsion of the atlanto-occipital articulation, and dislocation fractures of the cervical vertebrae with resulting transection of the spinal cord (21). The severity of injuries indicated that fatality was not directly attributable to the lap belt — that pelvic injuries did not produce death. Rather, it was presumed that lethal head-neck trauma was produced by the secondary impact with the padded floor of the sled.

Several investigators have attempted to correlate lethal head-neck injuries with head deceleration (17, 22). For investigation of this relationship, peak head angular decelerations and the peak linear resultants of the anterior accelerometer cluster occurring at the time of head contact with the floor of the sled were calculated for a 32 g sled deceleration. Respectively, these values were 256,000 deg/sec^2 and 147 g. However, the authors can offer no proof that fatality directly resulted from head angular or linear deceleration since lethal trauma may have resulted from hyperextension of the head-neck, skull fractures, translational or angular shear loading at the atlanto-occipital articulation.

Forces — The lap belt and seat coordinate values of x, y, and z refer to a left-handed rectangular Cartesian coordinate system where x is parallel to sled movement, y is lateral, and z is vertical. The recorded forces transmitted by the baboon to the lap belt, seat pan, and back were corrected

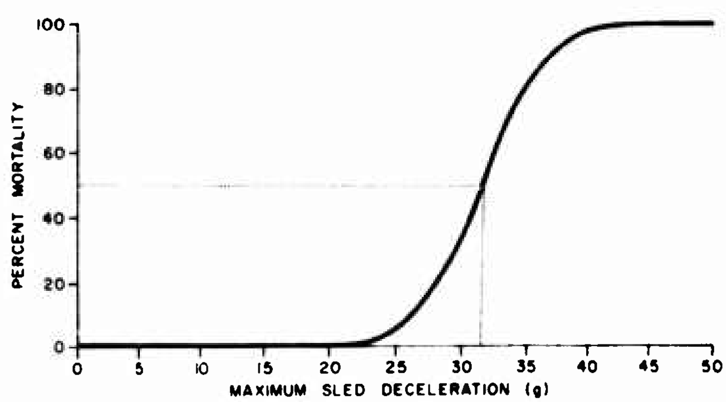

Fig. 5—Percent mortality versus maximum sled deceleration. Sigmoid curve derived from probit analysis

by subtraction of dynamic tare loads—the force/g attributable to the mass of the transducer system acting upon the active portion of the gage. Component forces were derived from the summation of right and left lap belt loads. Total lap belt force was calculated from the vector summation of the right and left belt x, y, and z force components.

Force-Time Events—A typical plot of force-time events is depicted in Fig. 6. Time zero was the instant of sled contact with the brake. The onset of the deceleration pulse started 8-20 ms later, depending upon sled velocity. Likewise, the baboon started to load the lap belt and seat pan approximately 10-20 ms after the initiation of the deceleration pulse.

The forces transmitted to the lap belt typically resulted in curves with three distinct peaks (Fig. 6). Documented by stop-motion photography, the initial peak occurred as the belt effectually snubbed the subject which was usually within 10 ms after peak sled deceleration. At this time the torso was nearly vertical and beginning to rotate around the belt (Fig. 19). The second major peak of the lap belt force curves was invaribly greater in magnitude than the first (Fig. 6). This peak occurred at the instant when the longitudinal axis of the rotating baboon torso became parallel to the axis of the lap belt (Fig. 19). The third lap belt peak occurred

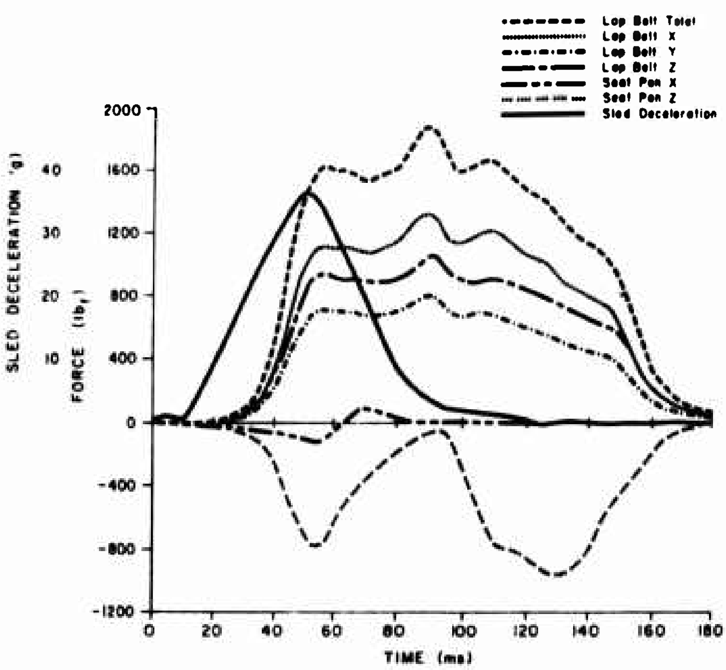

Fig. 6—Sled deceleration, lap belt, and seat pan forces versus time (run 4882)

when the longitudinal axis of the baboon torso was essentially horizontal (Figs. 6 and 19). This peak was particularly prominent in the *x* lap belt force component.

Simultaneously with the snubbing event, an appreciable force was transmitted to the seat pan in a downward direction (Fig. 6). The second negative peak in the seat pan down recording resulted after the baboon thorax contacted the thighs and thus transmitted force to the seat pan.

The force transmitted to the seat pan in the forward direction was due to friction between the seat pan and the baboon as the pelvis and legs translated forward.

Force-Deceleration Comparison — In Figs. 7-13, peak lap belt and seat pan forces are represented versus maximum sled deceleration. The forces were proportionately adjusted to reflect a standard 50 lb animal weight. Impulses were computed by integrating the force-time curves using 1 ms intervals from time zero until the baboon head contacted the floor of the sled. On all graphs the 90% confidence interval reflects the range of expected individual force or impulse values for a given sled deceleration (23)[4]. Results from future experiments conducted under similar conditions are expected to fall within this range 90% of the time.

---

[4]90% Confidence Interval $= \hat{Y} \pm t_{[(1.90/2)\ (n-2)]} \hat{s}_y$ (1)

where: $s_y^2 = s_E^2 \left(1 + \frac{1}{n} + \frac{(X-\bar{X})^2}{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}\right)$ (2)

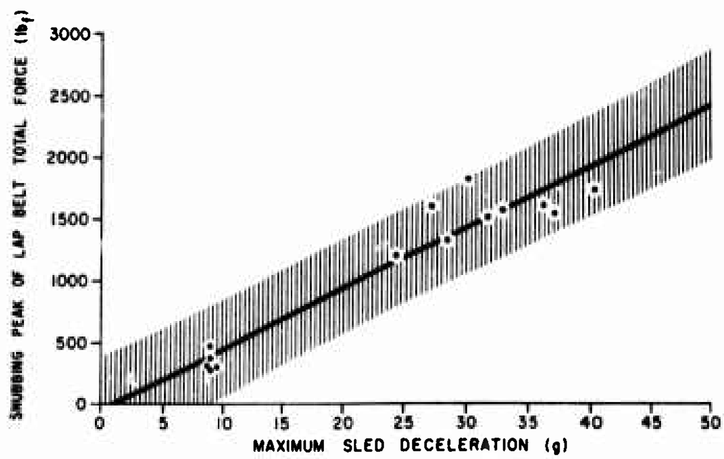

Fig. 7—Snubbing peak of lap belt total force versus maximum sled deceleration. Shaded area represents the 90% confidence interval

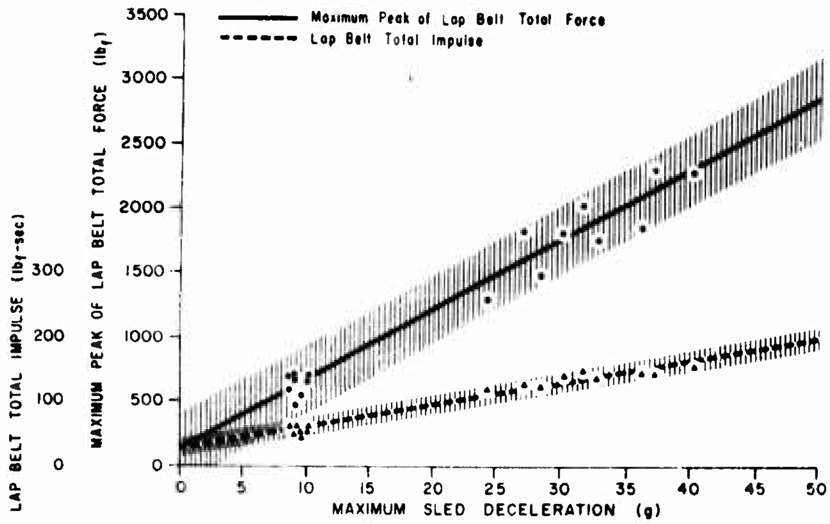

Fig. 8—Maximum peak of lap belt total force and impulse versus maximum sleo deceleration. Shaded area represents the 90% confidence interval

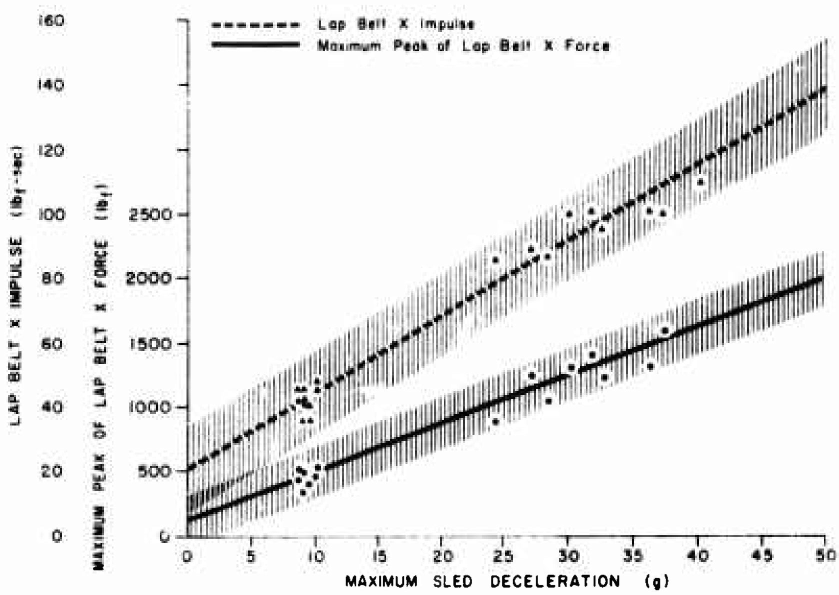

Fig. 9—Maximum peak of lap belt x force and impulse versus maximum sled deceleration. Shaded area represents the 90% confidence interval

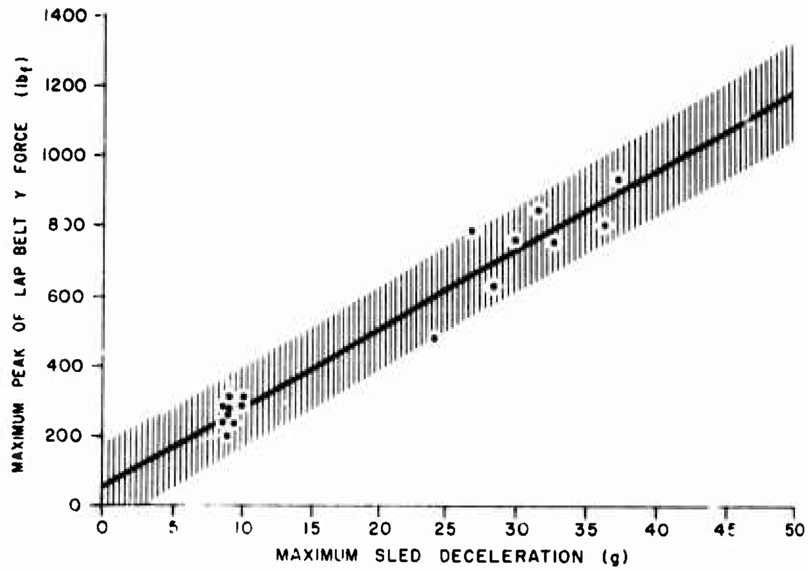

Fig. 10—Maximum peak of lap belt $\underline{y}$ force versus maximum sled deceleration. Shaded area represents the 90% confidence interval

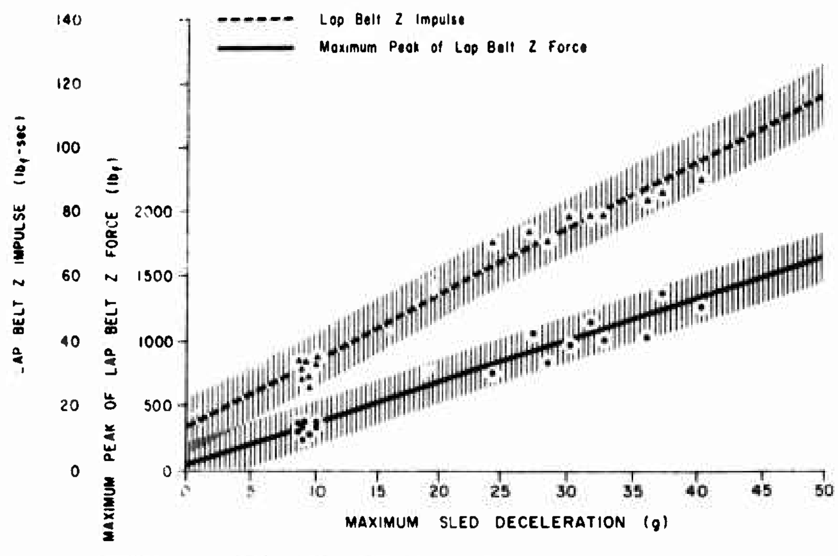

Fig. 11—Maximum peak of lap belt $\underline{z}$ force and impulse versus maximum sled deceleration. Shaded area represents the 90% confidence interval

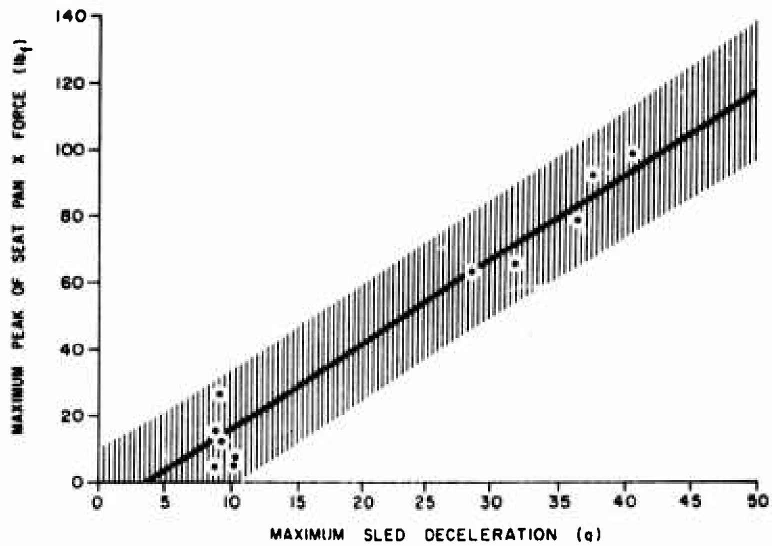

Fig. 12—Maximum peak of seat pan $\underline{x}$ force versus maximum sled deceleration. Shaded area represents the 90% confidence interval

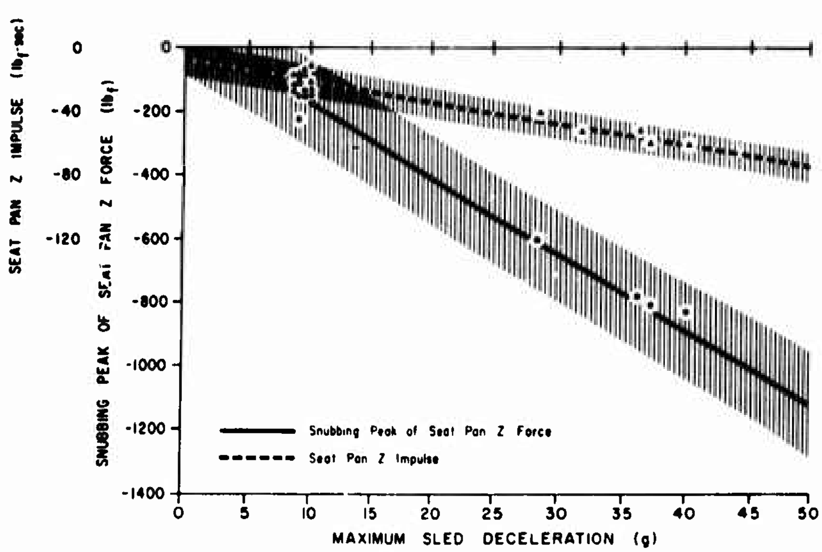

Fig. 13—Snubbing peak of seat pan $\underline{z}$ force and impulse versus maximum sled deceleration. Shaded area represents the 90% confidence interval

The equations of the linear regression lines and respective correlation coefficients are presented in Table 1. Excellent linear correlations were obtained in each case. The relatively small pan forward forces may possibly be due to the low coefficient of friction between the baboon and the plastic seat cover. On the graphs (Figs. 7-11), the finite forces on the lap belt ordinates at 0 g were partially due to pretensioning and to possible non-linearity of the regression line below 8.6 g.

Seat pan *y* values were typically less than 20 lb and random in occurrence. Seat back forces were negligible since the baboon did not rebound or "submarine" under the lap belt.

Head Angular Acceleration — The head reference axes may be depicted using a polar coordinate system where displacement of the head was positive with flexion and negative with hyperextension.

Figs. 14-16 graphically display the electronic and photographic results of acquiring head angular accelerations, velocities, and displacements. Although not fully evaluated for accuracy, it is postulated that the linear accelerometers were more accurate for the determination of head angular acceleration and velocity, whereas photographic analyses yielded more accurate head angular displacements. The basis for this postulation is that numerical differentiation is inherently a greater error-producing process than integration.

Table 1 — Equations of Force and Impulse Regression Lines

Ordinate	Equation of Regression Line	Linear Correlation Coefficient
Lap belt total (1st or snubbing peak)	Force[a] = −39.2 + 48.84 (g_{max})	0.9628
Lap belt total (2nd or maximum peak)	Force = 127.6 + 54.32 (g_{max})	0.9829
	Impulse[b] = 28.1 + 3.42 (g_{max})	0.9860
Lap belt x (2nd or maximum peak)	Force = 113.6 + 37.57 (g_{max})	0.9814
	Impulse = 20.6 + 2.37 (g_{max})	0.9788
Lap belt y (2nd or maximum peak)	Force = 52.7 + 22.70 (g_{max})	0.9786
Lap belt z (2nd or maximum peak)	Force = 41.2 + 32.23 (g_{max})	0.9808
	Impulse = 13.8 + 20.5 (g_{max})	0.9878
Seat pan x (maximum peak)	Force = 9.4 + 2.55 (g_{max})	0.9806
Seat pan z (1st or snubbing peak)	Force = 59.9 − 23.79 (g_{max})	−0.9799
	Impulse = −6.8 − 1.37 (g_{max})	−0.9753

[a]Units of force expressed in lb_f.
[b]Units of impulse expressed in lb_f·sec.

Using the accelerometer recordings, the maximum head angular and linear decelerations usually occurred when the head contacted the floor

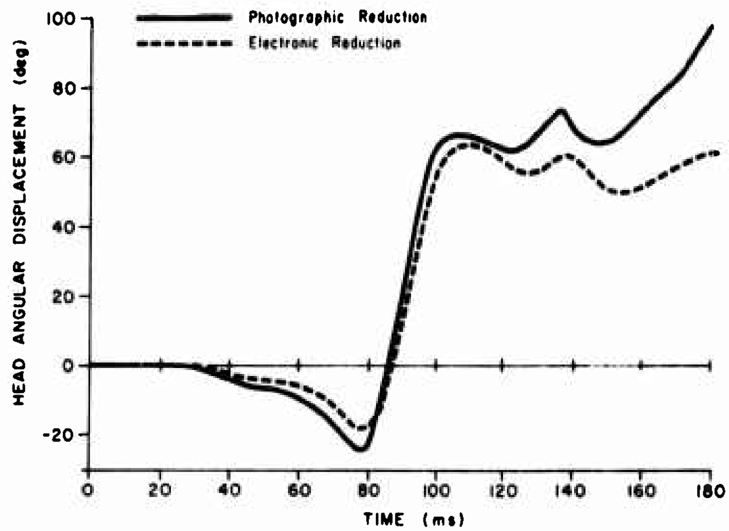

Fig. 14—Head angular displacement versus time. Electronic and photographic determination (run 4882)

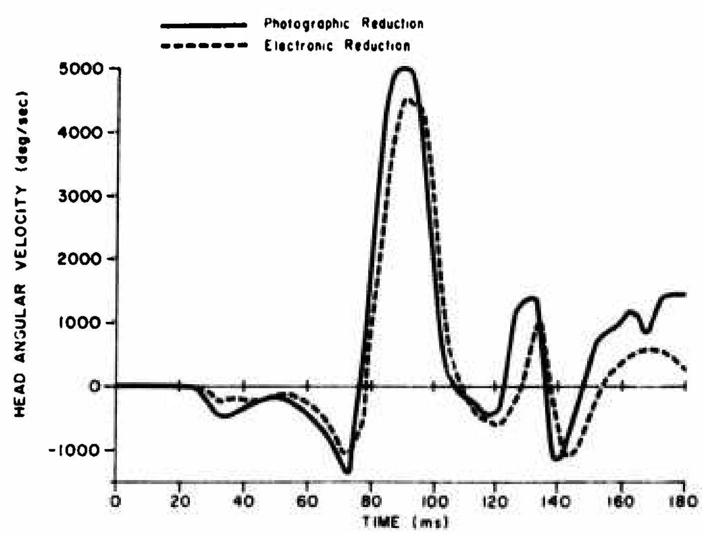

Fig. 15—Head angular velocity versus time. Electronic and photographic determination (run 4882)

of the sled. Regression lines were determined to delineate the relationship with maximum sled deceleration (Fig. 17). Likewise, maximum head

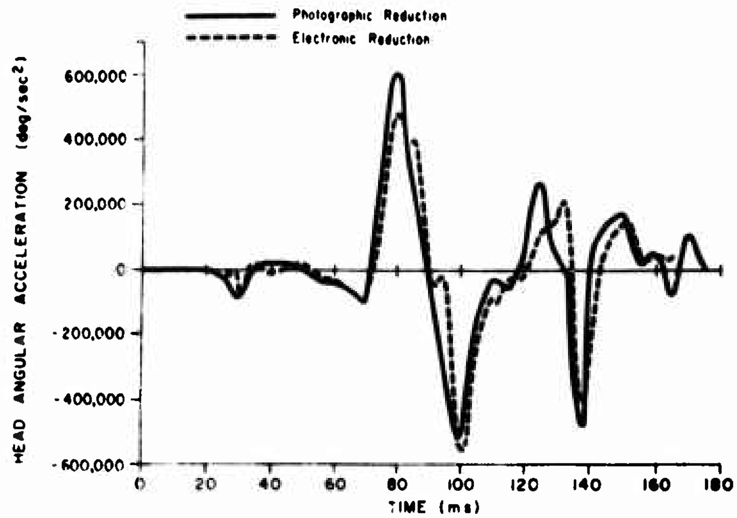

Fig. 16—Head angular acceleration versus time. Electronic and photographic determination (run 4882)

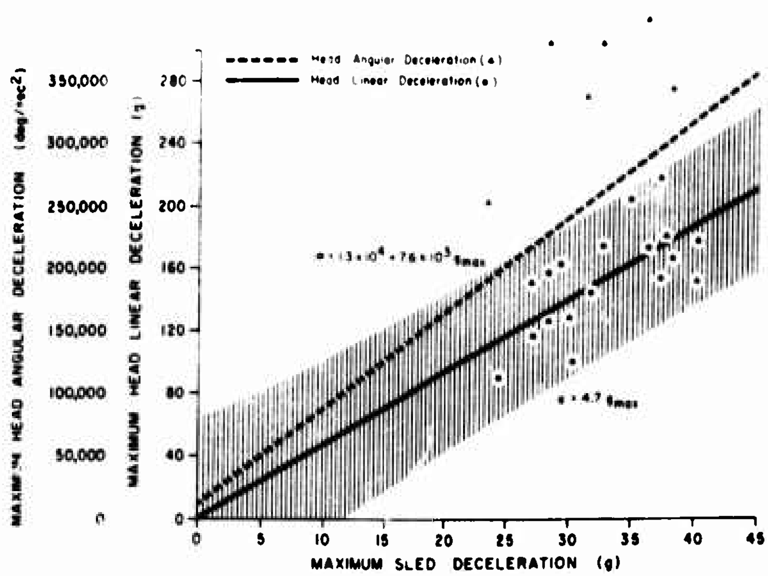

Fig. 17—Maximum head angular and linear decelerations versus maximum sled deceleration. Shaded area represents the 90% confidence interval for head linear deceleration

angular accelerations were plotted against peak sled deceleration (Fig. 18). For the wide range of sled decelerations, these maximal head angular accelerations occurred when the torso approached 60 deg from the vertical (Fig. 19).

Head-Torso Acceleration — Previous investigators (24, 25) have calculated head angular accelerations relative to the torso or vertebral column. As spatial head angular accelerations were reported in this study, it became essential for correlation purposes to determine whether significant differences in head angular accelerations were attributable to the reference system.

The angular displacement of the longitudinal axis of the baboon was determined from the high speed film (Fig. 19). Torso angular velocities and accelerations were then computed by numerical differentiation (Fig. 19).

The angles of the head with respect to the torso (Fig. 20) were determined by subtracting the torso (Fig. 19) from the head angular displacement function (Fig. 14). The head-torso displacement curve was differentiated twice to yield head-torso angular accelerations (Fig. 20).

Comparison of Fig. 16 with Fig. 20 shows that peak head angular accelerations may differ from head-torso angular accelerations by 100,000 deg/sec^2. This variation was attributable to the angular acceleration of the baboon torso.

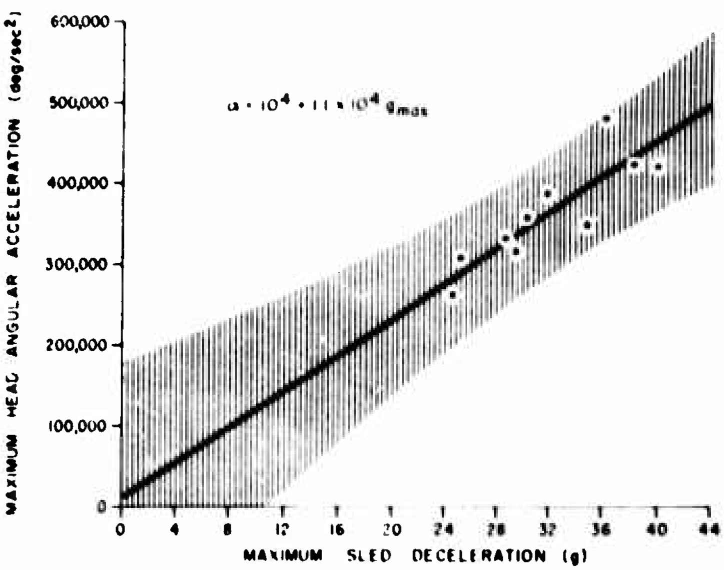

Fig. 18—Maximum head angular acceleration versus maximum sled deceleration. Shaded area represents the 90% confidence interval

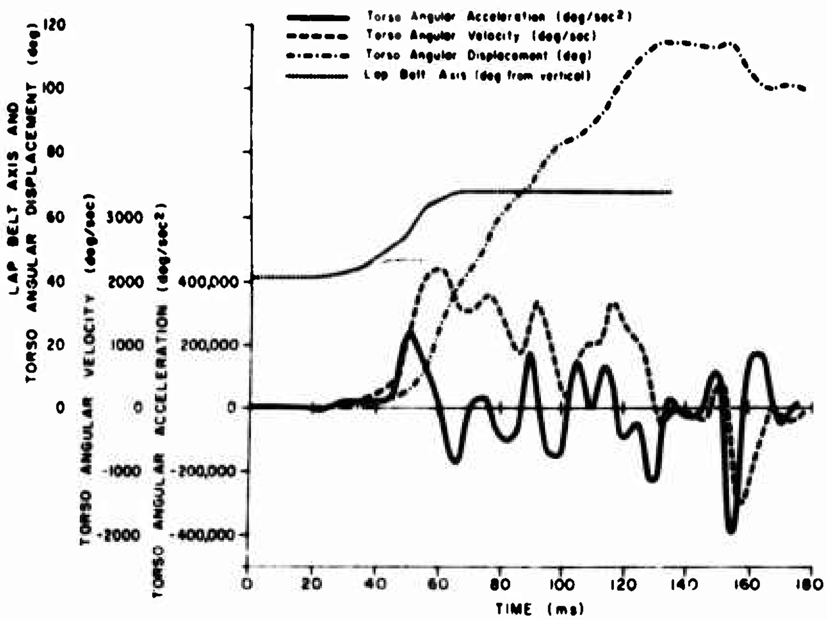

Fig. 19—Lap belt angle, torso angular displacement, torso angular velocity, and torso angular acceleration versus time (run 4882)

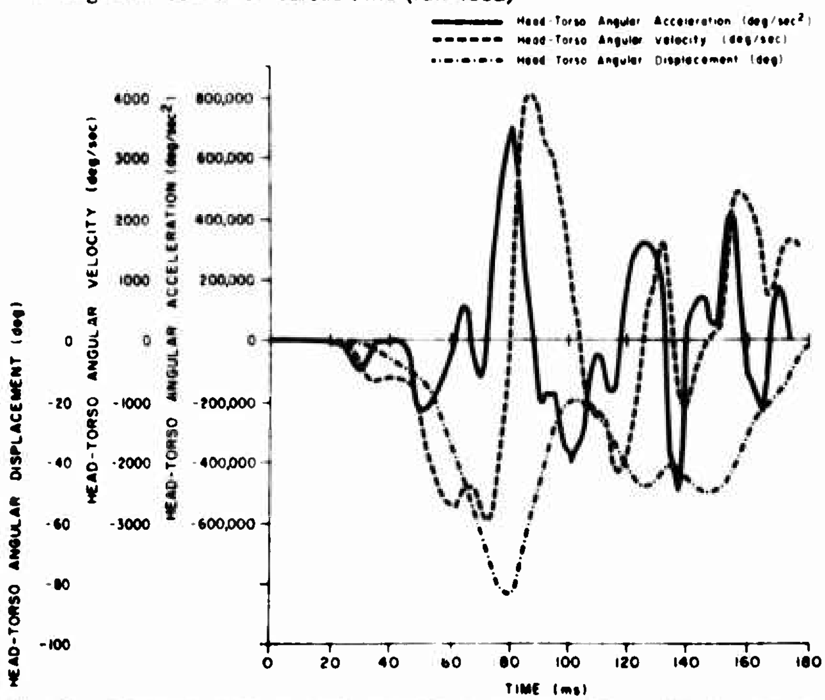

Fig. 20—Head-torso angular displacement, head-torso angular velocity, and head-torso angular acceleration versus time (run 4882)

Conclusions

The results indicate that for a lap belt restraint, peak sled decelerations can be correlated with tolerance to impact. The median lethal sled deceleration (LD_{50}) was calculated to be 32 ± 4 g. Although tolerance was expressed as a function of sled deceleration, trauma to the head-neck was the weak link which limited the survival to whole body impact decelerations. The mechanisms of these injuries may always lack the simplicity of a common denominator. Additional efforts to protect the head from trauma are essential.

Both head angular acceleration and velocity curves showed similarities in shape and phase relationship extending over a 30 g sled deceleration range. Linear regression analysis demonstrated the amplification relationship of peak head angular accelerations to maximum sled decelerations. It appears feasible that descriptive equations can be written to generalize these findings.

The lap belt and seat pan forces and impulses were in linear agreement with maximum sled decelerations. The fully instrumented seat and restraint system has application as an excellent tool for the analytical evaluation of forces transmitted to the restraint as well as for the approximation of various subject positions during the impact event.

Acknowledgment

We acknowledge with sincere gratitude the ever present guidance and support of Doyle D. Rexrode, Digital Computation Branch, MDRC. His technical insight and scientific curiosity were a constant source of encouragement.

The entire Daisy Decelerator staff of the Land-Air Division, Dynalectron Corp., deserves commendation for their support in the completion of this project.

Portions of this project were funded under contract with the U. S. Department of Transportation.

References

1. G. Nichols, "Analysis and Biodynamics of Selected Rocket-Sled Experiments." Part II, Dynamic Response of Restrained Subject During Abrupt Deceleration. Brooks Air Force Base, Texas (SAM), DDC AD 609 412, 1964.

2. J. P. Stapp, J. D. Mosely, C. F. Lombard, and G. A. Nelson, "Analysis and Biodynamics of Selected Rocket-Sled Experiments." Part I, Biodynamics of Maximal Decelerations. Brooks Air Force Base, Texas (SAM), DDC AD 609 412, 1964.

3. J. P. Stapp, "Human Exposure to Linear Deceleration." Part 1, Preliminary Survey of Aft-Facing Seated Position. Wright-Patterson AFB, Ohio, AF-TR-5914, 1949, pp. 1-36.

4. J. P. Stapp, "Human Exposures to Linear Deceleration." Part 2, The Forward-Facing Position and the Development of a Crash Harness. Wright-Patterson AFB, Ohio, WADC-TR-5915, 1951, pp. 1-149.

5. J. P. Stapp, E. R. Taylor, and R. F. Chandler, "Effects of Pitch Angle on Impact Tolerance." Proceedings of Seventh Stapp Car Crash Conference, Springfield, Ill.: Charles C Thomas, Publisher, 1965.

6. C. Tarriere, "Analysis of Interrelation of Vehicle to Seat Belt as a Function of Rigidity of the Vehicle." Proceedings of Twelfth Stapp Car Crash Conference, P-26, paper 680777. New York: Society of Automotive Engineers, Inc., 1968.

7. R. F. Chandler and R. A. Christian, "Comparative Evaluation of Dummy Performance Under $-G_x$ Impact." Proceedings of Thirteenth Stapp Car Crash Conference, P-28, paper 690798. New York: Society of Automotive Engineers Inc., 1969.

8. R. G. Snyder, C. C. Snow, J. W. Young, G. T. Price, and P. Hanson, "Experimental Comparison of Trauma in Lateral ($+G_y$), Rearward Facing ($+G_x$) and Forward Facing ($-G_x$) Body Orientations When Restrained by Lap Belt Only." Aerospace Medicine, 1967, Vol. 38, pp. 889-894.

9. R. G. Snyder, C. C. Snow, J. W. Young, W. M. Crosby, and G. T. Price, "Pathology of Trauma Attributed to Restraint Systems in Crash Impacts." Aerospace Medicine, 1968, Vol. 39, pp. 812-829.

10. R. W. Armstrong, H. P. Waters, and J. P. Stapp, "Human Muscular Restraint During Sled Deceleration." Proceedings of Twelfth Stapp Car Crash Conference, P-26, paper 680793. New York: Society of Automotive Engineers, Inc., 1968.

11. W. J. Dixon and A. M. Mood, "A Method for Obtaining and Analyzing Sensitivity Data." J. Amer. State. Assn., 1948, Vol. 43, pp. 109-126.

12. A. W. Kimball, W. T. Burnett, Jr. and D. G. Doherty, "Chemical Protection Against Ionizing Radiation. 1. Sampling Methods for Screening Compounds Radiation Protection Studies with Mice." Radiation Research, Vol. 7 (1957), pp. 1-12.

13. R. F. Chandler, "The Daisy Decelerator." ARL-TDR-67-3, Holloman AFB, New Mexico, 1967.

14. C. D. Bendixen, "Measurement of Head Angular Acceleration During Impact." ARL-TR-70-5, Holloman AFB, New Mexico, 1970.

15. M. Kornhauser and R. W. Lawton, "Impact Tolerance of Mammals." Proceedings of the Fourth AFBMD/STL Symposium, Advances in

Ballistic Missile and Space Technology, Vol. 3. Oxford: Pergamon Press, 1961, pp. 386-394.

16. A. J. Gold, H. E. Hance, M. Kornhauser, and R. W. Lawton, "Impact Tolerance of Restrained Mice as a Function of Velocity Change and Average Deceleration." Aerospace Medicine, 1962, Vol. 33, pp. 204-208.

17. C. F. Lombard, W. A. Robbins, and C. L. Potter, "Some Factors Contributing to Head and Neck Injuries During Whole Body Impact Using Guinea Pig Subjects in $\pm$ G_x Orientations." Proceedings of Twelfth Stapp Car Crash Conference, P-26, paper 680787, New York: Society of Automotive Engineers, Inc., 1968.

18. A. Goldstein, "Biostatistics." New York: The MacMillan Co., 1964, pp. 172-178.

19. J. S. Williams, B. A. Lies, Jr., and H. W. Hale, Jr., "The Automotive Safety Belt: in Saving a Life May Produce Intra-Abdominal Injuries." J. Trauma, 1966, Vol. 6, pp. 303-315.

20. F. A. Traylor, W. W. Morgan, Jr., J. I. Lucero, and J. C. Owens, "Abdominal Trauma from Seat Belts." Amer. Surg., 1969, Vol. 35, pp. 313-316.

21. T. D. Clarke, "Department of Transportation. Daisy Track Baboon Lethal Tolerance Tests." 6571st Aeromedical Research Laboratory, Holloman AFB, New Mexico, 1970.

22. J. J. Swearingen, "Tolerances of the Human Face to Crash Impact." Oklahoma City, Okla.: Federal Aviation Agency, Office of Aviation Medicine, CARI, AM 65-20, 1965.

23. B. Ostle, "Statistics in Research." Iowa State University Press, 1963, Chapters 8 and 9.

24. J. L. Martinez, "Headrest and Seat Back Design Proposals." Proceedings of Twelfth Stapp Car Crash Conference, P-26, paper 680775, New York: Society of Automotive Engineers, Inc., 1968.

25. C. L. Ewing, D. J. Thomas, L. M. Patrick, G. W. Beeler, and M. J. Smith, "Living Human Dynamic Response to $-G_x$ Impact Acceleration. Part II. Accelerations Measured on the Head and Neck." Proceedings of Thirteenth Stapp Car Crash Conference, P-28, paper 690817, New York: Society of Automotive Engineers, Inc., 1969.

U.S. Government Printing Office: 197? — 759-085/550